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Comparison of drinking water pollutant removal using a nanofiltration pilot plant powered by renewable energy and a conventional treatment facility

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HIGHLIGHTS

- We compare drinking water treatment systems, a NF unit and a conventional treatment.
- Sustainable water quality improvement using renewable energy is demonstrated.
- Membranes are more efficient than conventional treatment removing micropollutants.
- Membranes reject hydrophobic compounds causing the permeate becomes more hydrophilic.

GRAPHICAL ABSTRACT

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ABSTRACT

In this paper, drinking water pollutant removal between a conventional drinking water treatment and a nanofiltration (NF) pilot plant powered by renewable energy is compared. This kind of plant can be very useful for isolated locations with water quality problems. Energy consumption and related CO_2 emissions and the occurrence of synthetic organic compounds in drinking water sources are important environmental and public health issues. NF membranes were used to improve drinking water quality from a holistic point of view. Compared to conventional drinking water treatment, membranes efficiently removed color and turbidity (100%), DOC (93%), ions (97%), and metals and metalloids (ranging from 80% to 100%), but not boron (17%) or pharmaceuticals (Ph's) (varied from 15% to 100%, but still always above conventional treatment). Moreover, NF membranes removed 53% of the trihalomethanes (THMs) present in conventionally treated water. Analyses of 93 persistent organic compounds (VOCs, BTEXs, PAHs, DEs, pesticides…) were carried out, but none of the compounds were detected in the three types of water analyzed (reservoir, conventionally treatment and NF permeate). Reservoir water has a strong hydrophilic composition due to protein-like substances that can promote biofouling. NF membranes effectively removed the hydrophobic fraction (66%).

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1. Introduction

Desalination technologies are attracting great interest for their potential to solve water shortage and water quality problems. The desalination market is growing especially, but not only, in arid and semiarid areas due to its implementation in both industries and municipal drinking water facilities that require high-quality water production. From an environmental point of view, however, desalination is an energy-intensive process. When fossil fuels are used, the energy consumed for membrane desalination contributes to increase CO_2 emissions and therefore to the critical environmental issue of climate change. The use of desalination powered by renewable energy (RE) is an increasing trend, especially in arid and semiarid areas due to the potential of these areas for renewable energy production [1]. It is also an interesting alternative for those remote locations far away of electricity grids. As Ghermandi and Messalem [2] stated, the coupling of desalination and RE has two main advantages: (i) it improves the process' sustainability by minimizing or completely eliminating the use of fossil fuels and (ii) it significantly reduces the operational costs of desalination plants. There are two main renewable energy sources for desalination, wind and sun, although other sources can be used to a minor degree. Due to the discontinuity problems inherent in these renewable energy sources—based on daylight periods for solar systems and wind speed for wind systems—hybrid desalination systems are designed to combine the power outputs of both systems. With an appropriate design, the number of hours of daily operation is extended [3], or else surplus energy is stored as backup to ensure steady operation during periods of low or intermittent solar radiation or low wind speeds. The use of batteries for electricity storage increases the autonomy of these systems. Experimental units built in Spain [4], Israel [5] and Greece [6] demonstrated the technical feasibility of the concept and the possibility of long-term operation with minimal maintenance [2].

Desalination membrane technology also shows potential for cleaning polluted drinking water sources and improving water quality. Drinking water sources are threatened by the presence of synthetic organic compounds coming from treated and non-treated effluents and diffuse contamination. These pollutants are of high concern because their environmental fates, behaviors and metabolites are not well-known [7,8]. Great effort has been made in recent years to successfully reduce persistent organic pollutants (POPs) occurrence, but newly emerging trace organic contaminants such as endocrine disruptors (EDs), personal care products (PCPs) and pharmaceuticals (Ph's) are forcing the scientific community to find new solutions that will reduce these contaminants' occurrence in drinking water. Although these compounds usually appear in aquatic environments at very low concentrations (parts per billion or parts per trillion), they do so consistently due to their frequent use by today's consumers. Trihalomethanes (THMs), which are by-products of chlorination, are other compounds of concern [9–15]. These carcinogenic compounds are produced during drinking water treatment when low molecular weight organic compounds, present in raw water, react with chlorine, which is used for disinfection. Several studies have shown that conventional wastewater treatment is ineffective at removing these contaminants and that conventional drinking water treatments have limited effectiveness [16–18]. Only activated carbon (AC) and membrane processes like NF and RO are effective at removing these compounds from water. NF removes organic matter as efficiently as RO [19] and, depending on the membrane, also shows high recovery, good salt rejection and lower energy consumption than RO.

The main objective of this study was to compare the removal of trace organic compounds in a municipal drinking water treatment plant (MDWTP) and in a NF pilot plant powered by renewable energy (wind mills and photovoltaic (PV).

The pilot plant used in this work was built for the ETAPERN Project (acronym of assessment of drinking water treatment using NF powered by RE, in English). The main goals of this project were, 1) to study the potential of NF to improve water quality from a holistic point of view, 2) to use RE resources, abundant in Andalusia and 3) to complement or replace the conventional treatment scheme.

2. Materials and methods

2.1. System characteristics

The pilot plant is located in the El Montañés MDWTP in Puerto Real, Cadiz, south of Spain. This facility treats water from a reservoir and serves a population of 400,000 inhabitants of the Bay of Cadiz. The pilot plant consists of a NF unit which can work in one, two or three stages and is powered exclusively by a hybrid wind mills–photovoltaic RE system. The plant also has a fuel cell, but it has not been considered in this study. The plant is located inside a standard 40-foot container so it can be delivered anywhere. The NF unit has three pressure vessels containing four membrane modules each, for a total of twelve NF90 4040 NF membranes (Film-Tec Dow Chemical Company, USA). These are spiral wound membranes with a total active area of 7.6 m^2 each and a molecular weight cut off of 200 Da. Two high pressure pumps (CR3-17, Grundfoss, Denmark) use Variable Speed Drives (ABB, Germany) for energy consumption reduction. In order to reduce even more the energy consumption, there is no intermediate pumping between the feed water tank and high pressure pumps. A 5-μm microfiltration cartridge system is located between high pressure pumps and pressure vessels. Chlorine in excess is removed using sodium bisulfite. All pipes are made of 316L stainless steel. The pilot plant scheme is shown in Fig. 1.

The wind energy system comprises two windmills of 3.0 kW each (Inclin3000, Bornay, Alicante, Spain) with wingspans of 4.0 m. The horizontal axis is elevated at 15 m. Energy production is controlled by electronic regulators (Inclin Dig. Reg., Bornay, Alicante, Spain). The PV system consists of 20 monocrystalline photovoltaic modules of 210 W each (SPR-210-WHT-I, Sunpower, San Jose, California, USA) with an installed power of 4.2 kWp. The array is fixed in place facing south and tilted at 31 degrees. The PV electronic charge regulator is an Outback Power System (Flexmax 80, Arlington, WA, USA). The collected energy is stored in a battery unit (Tudor, Alcobendas, Madrid, Spain) comprising four vessels in a parallel-series array with a total capacity of 2000 Ah. Continuous current from renewable energy sources (CC) is converted to discontinuous current (DC) by a 7.0 kW inverter (model 8000-48, HP Compact, China). Electricity production and consumption data are collected once per minute.

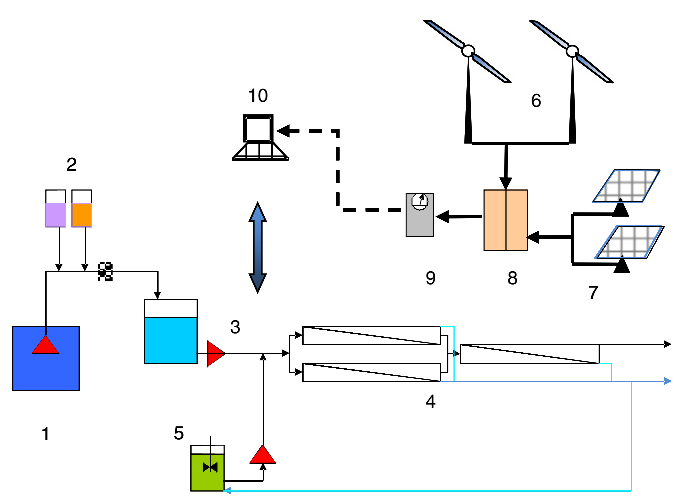

Fig. 1. Scheme of the pilot plant showing RE and NF units. 1: treated drinking water tank; 2: antiscaling and sodium bisulfite tanks; 3: high pressure pumps; 4: pressure vessels; 5: flushing system; 6: windmills; 7: photovoltaic field; 8: battery; 9: CC/DC inverter; and 10: control.